

LA-UR-12-20227

Approved for public release; distribution is unlimited.

Title: Nuclear EMP simulation for large-scale urban environments – Houston. FDTD for electrically large problems.

Author(s): Smith, William S.
Bos, Randall J.
Bull, Jeffrey S.
Wilcox, Trevor
Shao, Xuan-Min
Goorley, John T.
Costigan, Keeley R.
Colestock, Patrick L.
Drewniak, James
Razmadze, Alexander

Intended for: Modeling and Analysis Coordination Working Group IPAWS EMP Response Issues Resolution Meeting, 2012-03-28/2012-03-30 (Albuquerque, New Mexico, United States)



Disclaimer:

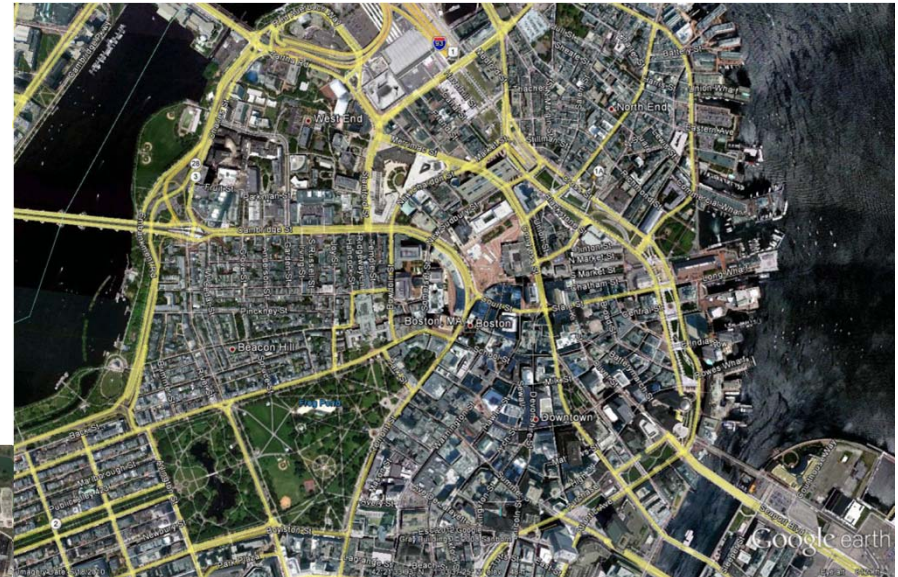
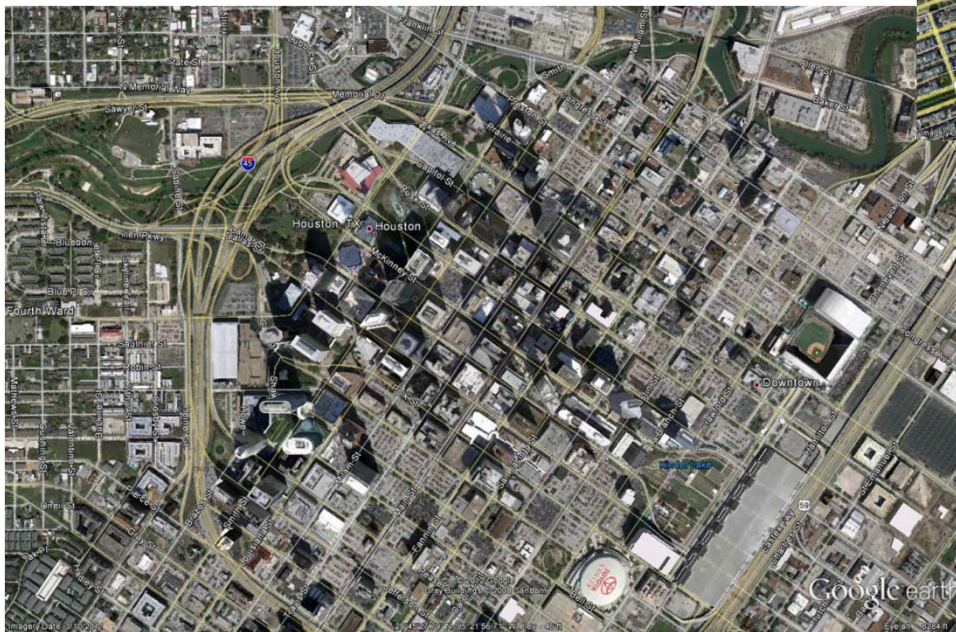
Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the Los Alamos National Security, LLC for the National Nuclear Security Administration of the U.S. Department of Energy under contract DE-AC52-06NA25396. By approving this article, the publisher recognizes that the U.S. Government retains nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

Abstract

In case of a terrorist nuclear attack in a metropolitan area, EMP measurement could provide a prompt confirmation of the nature of the explosion (chemical or nuclear) for emergency response, and characterization parameters of the device (reaction history, yield) for technical forensics. However, the urban environment affects the fidelity of the prompt EMP measurement (as well as all other types of prompt measurement). The nuclear EMP wavefront would no longer be coherent, due to incoherent production, attenuation, and propagation of gamma and electrons. EMP propagation from source region outward would undergo complicated transmission, reflection, and diffraction processes. A coupled MCNP/FDTD (Finite-difference time domain Maxwell solver) model has been developed to simulate the EMP in this complex environment. Electron currents are passed from an MCNP simulation of an urban area to an FDTD code that simulates the EMP propagation. The EMP propagation due to a NUDET (nuclear detonation) in downtown Houston is demonstrated and analyzed.

Nuclear EMP simulation for large-scale urban environments – Houston.

FDTD for electrically large problems.



Scott Smith, Randy Bos, Jeff Bull
Trevor Wilcox, Xuan-Min Shao, Tim Goorley, Keeley Costigan, Pat
Colestock
Jim Drewniak, Alexander Razmadze (MST)

Los Alamos National Laboratory

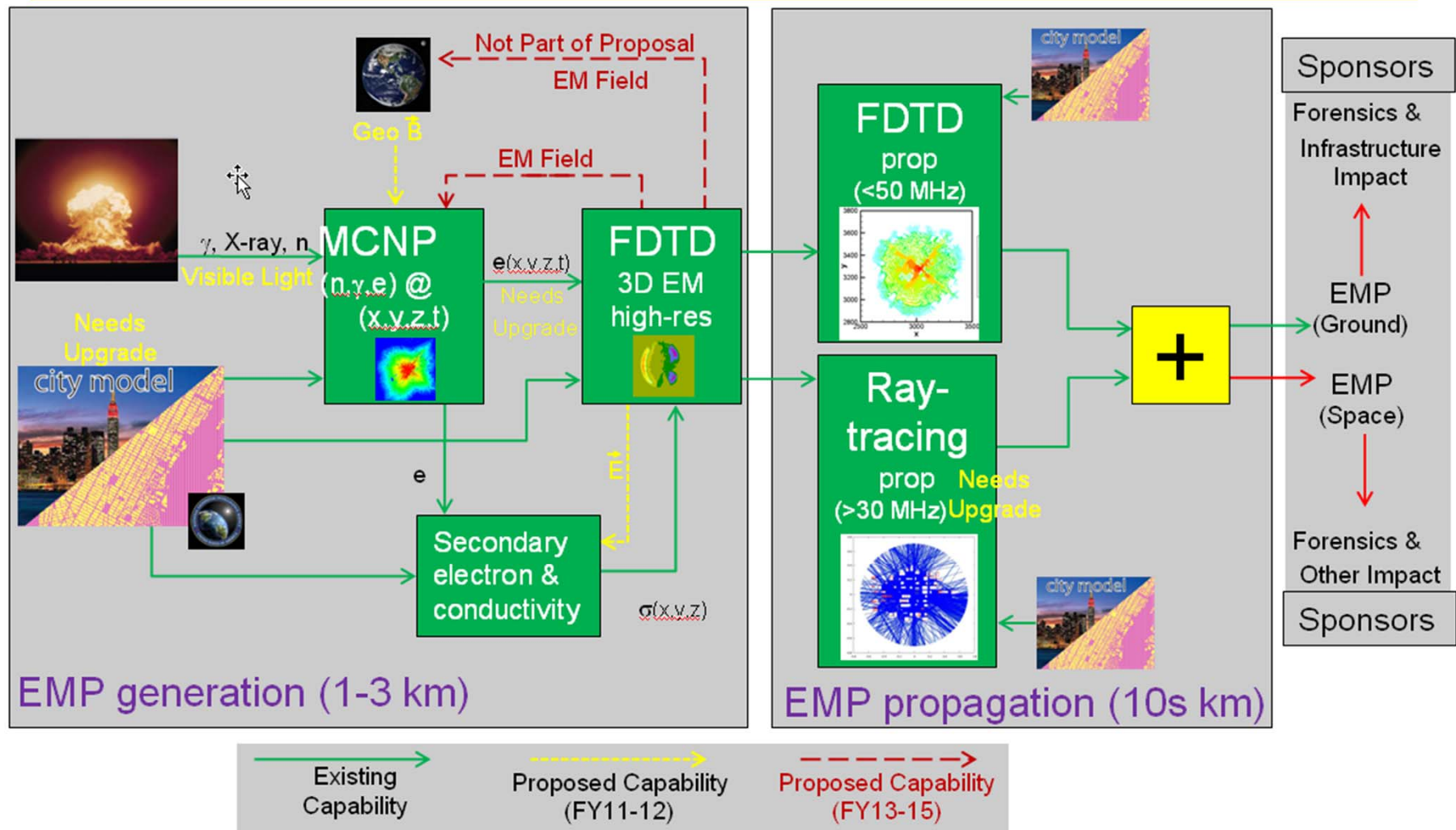
wss@lanl.gov

Modeling and Analysis Coordination Working Group
IPAWS EMP Response Issues Resolution Meeting
March 28-30, 2012, Sandia National Laboratories
Albuquerque, New Mexico

Background

- **In case of a terrorist nuclear attack in a metropolitan area, EMP measurement could provide**
 - a prompt confirmation of the nature of the explosion (chemical or nuclear) for emergency response
 - and characterization parameters of the device (reaction history, yield) for technical forensics
- **However, urban environment could affect the fidelity of the prompt EMP measurement (as well as all other types of prompt measurement)**
 - Nuclear EMP wavefront would no longer be coherent, due to incoherent production, attenuation, and propagation of gamma and electrons
 - EMP propagation from source region outward would undergo complicated transmission, reflection, and diffraction processes
- **EMP simulation for electrically-large urban environment**
 - Coupled MCNP/FDTD (Finite-difference time domain Maxwell solver) approach
 - FDTD tends to be limited to problems that are not “too” large compared to the wavelengths of interest because of numerical dispersion and anisotropy. So we must make it better.

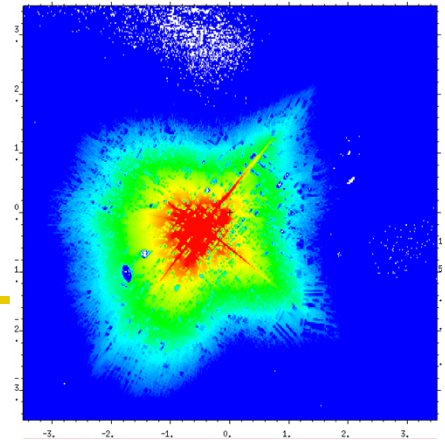
Approach flowchart



Scope of presentation

- Review the MCNP/FDTD tools and package elements
 - MCNP
 - Secondary electron package (conductivity)
 - FDTD and ray tracing
- Houston Urban NUDET EMP simulation
 - Model construction
 - FDTD results

MCNP capabilities



- Coupled Neutron Photon Electron Transport
 - Photon and Electron Transport $1 \text{ keV} < 100 \text{ GeV}$
 - Photon processes (pair production, Compton & coherent scattering, photo-electric)
 - Electron processes (scattering, energy and angle straggling, bremsstrahlung)
 - Atomic De-excitation (X-rays, Auger electrons)
 - Magnetic Fields for charged particles (under test for large-scale problem)
- Geometry
 - 3-D solid body
 - Regular repeated structured (lattice)
 - Unstructured mesh (under development)
 - Import city-specific data from NGA
- Calculate quantities of interest
 - Flux, current, energy deposition as a function of space, time and energy
- Parallel execution
 - mpi and shared-memory threading

FDTD with inputs from MCNP

Time/spacing varying current and air conductivity

($\Delta x, \Delta y, \Delta z=1\text{m}, \Delta t=1.7\text{ ns}$)

Secondary electron – ion package based on existing legacy (Unimax, HEMPV) code:

- secondary electron production
- Electron avalanche
- 2,3-body attachment
- Electron-ion
- ion-ion recombination

$$\frac{\partial n_+}{\partial t} = r_p n_p + r_s n_p + r_v n_s - \alpha_r n_s n_+ - \alpha_i n_+ n_-$$

$$\frac{\partial n_-}{\partial t} = \alpha n_s - \alpha_i n_+ n_-$$

$$\frac{\partial n_s}{\partial t} - \frac{1}{e} \nabla \cdot J_s = r_s n_p + r_v n_s - \alpha n_s - \alpha_r n_s n_+$$

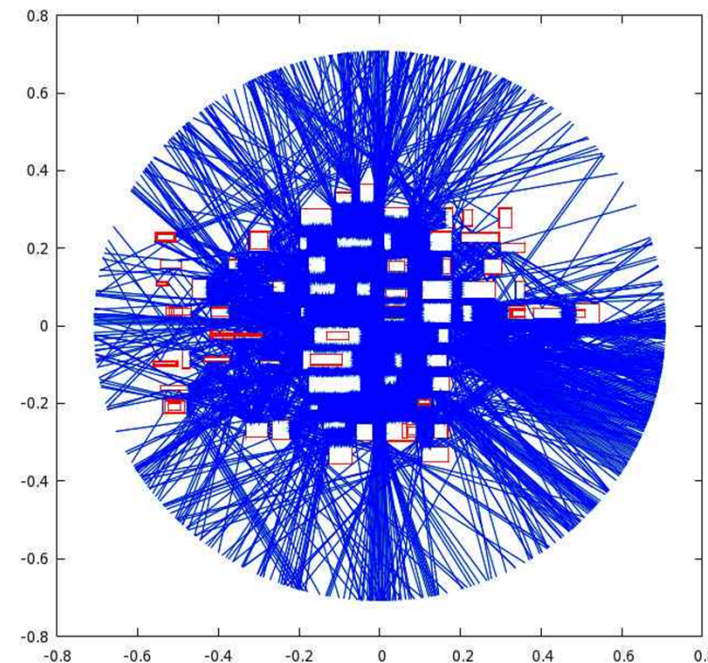
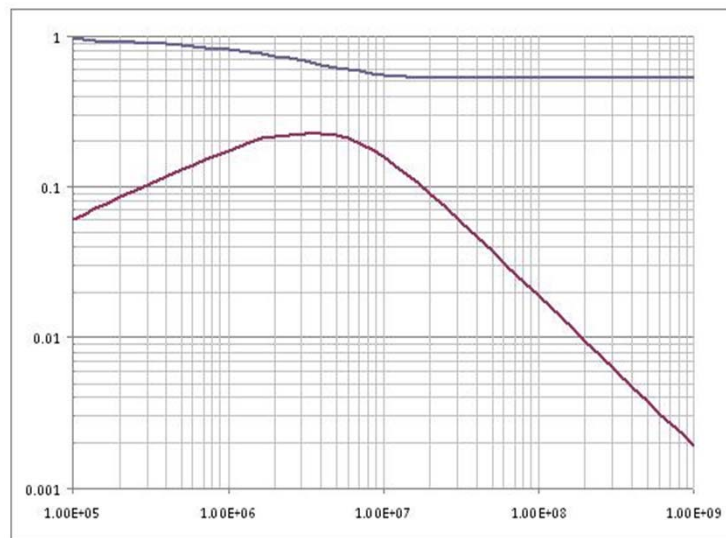
$$-e \frac{\partial (n_p)}{\partial t} + \nabla \cdot (J_p) = -e (r_p n_p)$$

$$\frac{\partial n_s}{\partial t} = r_s n_p + r_v n_s - \alpha n_s - \alpha_r n_s n_+$$

A Geometric Optics Model of Urban Propagation

- Valid for wavelengths shorter than average surface features
- Based on specular reflection at material surfaces
- Frequency dependence derives from reflection coefficient
- Fully three-dimensional field reconstruction
- Spatially-distributed (hemisphere) and temporally evolving EM sources

Reflection coefficient of concrete



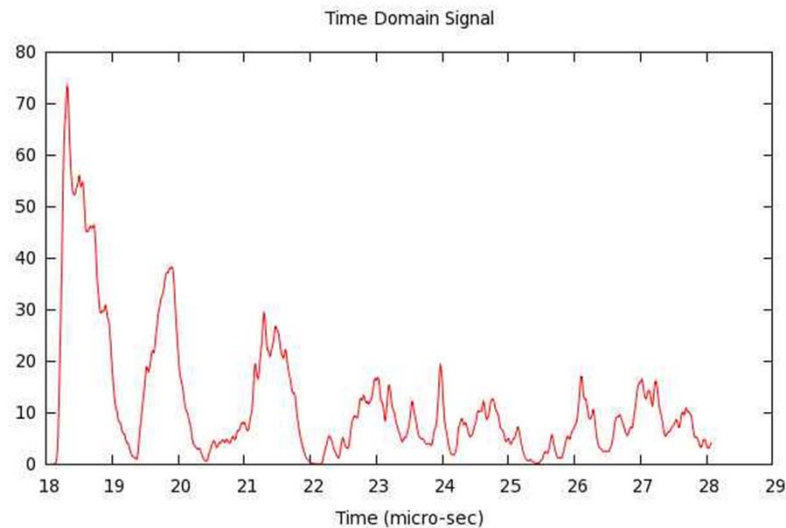
Times Square
Digitized Model:
200 bldgs.

Source at
(0,0,0)

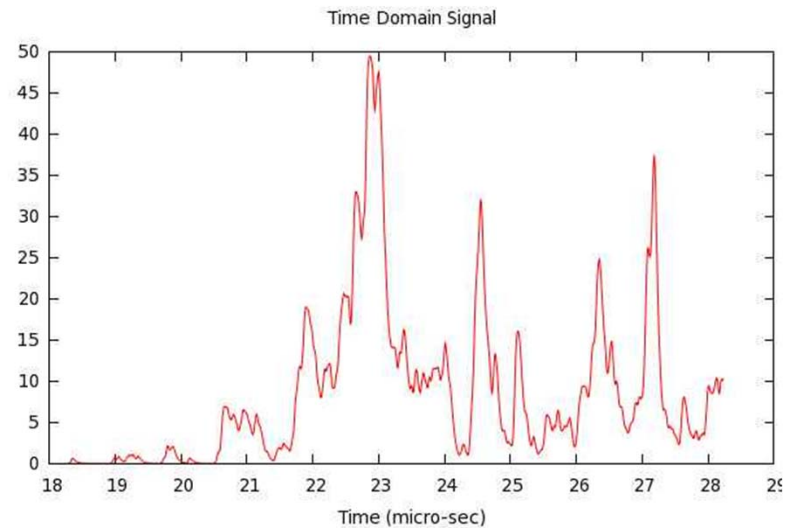
Composite Time Domain

(for point source at Time Squares)

Near zenith



Near ground

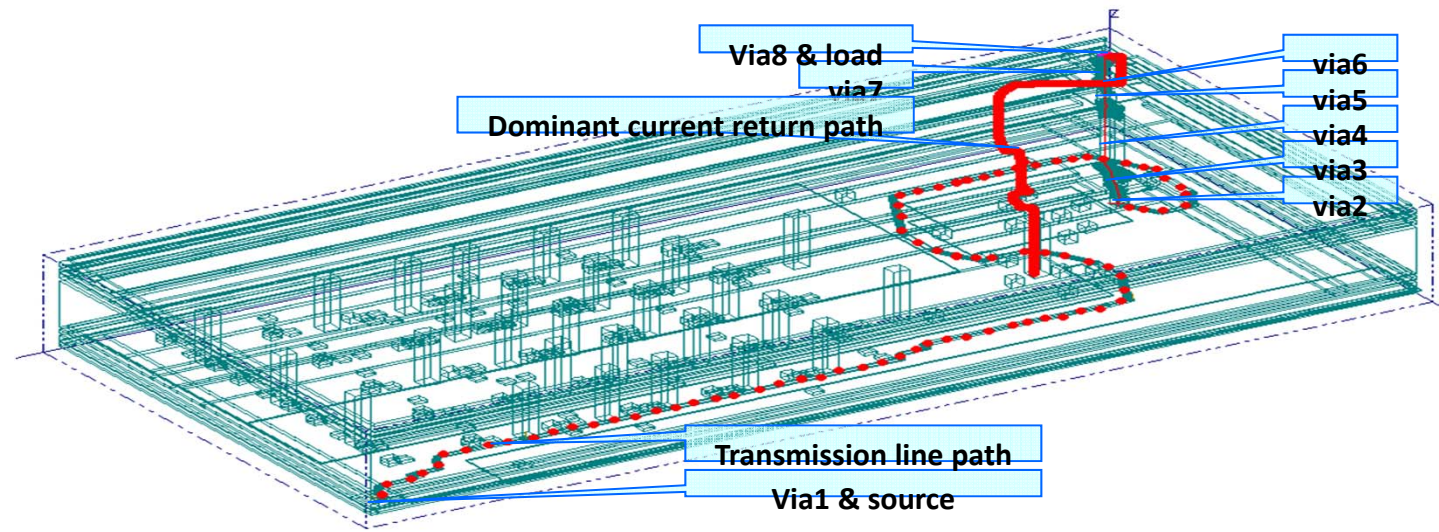
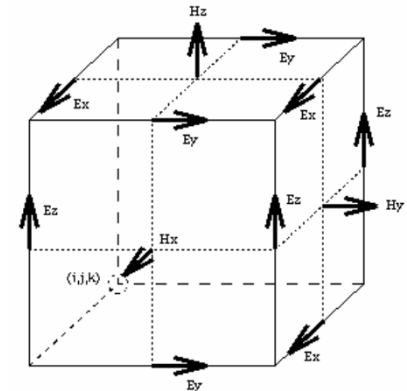


FDTD Functionality

Solve complex EM problems over a wide frequency range

ezFDTD code from MST (Missouri Science and Technology Institute)

Designed for small-scale studies (circuit board EM interactions)
Three-Dimensional Full-wave modeling
User-friendly GUI
Time- and frequency-domain results
Electric and magnetic fields



FDTD features

(EZ-FDTD, MST functions for modeling wave propagation in an urban environment)

Features	Parallel Version (2D)
PML, LIAO, CPML	needs checking
PEC	√
Normal Dielectric	√
Current/Voltage Probe	√
E/H Field Monitor (Probe)	√
Infinite ground plane	
Vent holes	needs checking
Far Field Probe	
Plane wave source	
Other Sources	√
Multi-Debye	√
Lorentz	
Thin slot	needs checking
Thin wire	needs checking
Lumped-Element	√
S-parameter block	
Thin layer	√

We are porting many of the sub-grid algorithms to the LANL FDTD code.

LANL FDTD is :

- 1) Simpler
- 2) Already plugged into MCNP as a subroutine

Wave form propagation over distance for selected algorithms

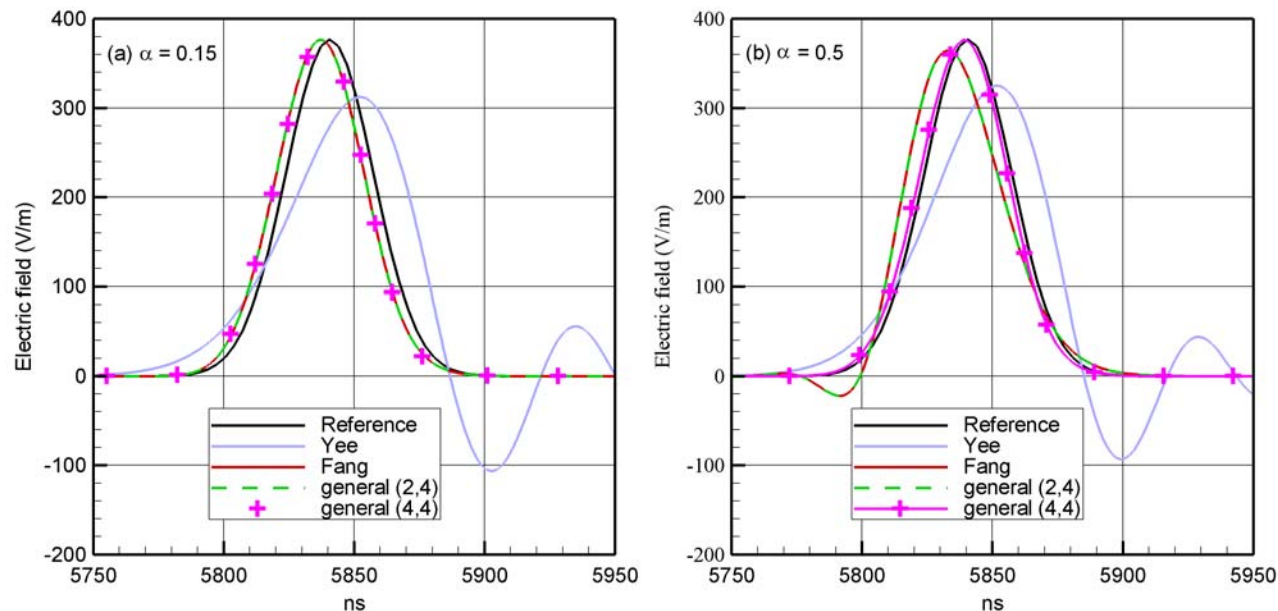


Fig. 1. Propagation of planewave gaussian waveform. Yee (2,2), Fang (2,4), general (2,4), and general (4,4) algorithms are compared to the original Gaussian waveform (yeeref in the legend) at 1780m from source. The x-axis is nano-seconds and the y-axis is z-component of the electric field in $V\ m^{-1}$. (a) Gaussian pulse propagated with $\alpha=0.15$. All of the schemes with 4th order spatial accuracy retain the pulse shape compared to the reference Gaussian pulse. (b) Same, but $\alpha=0.5$. The Fang and general (2,4) schemes exhibit similar dispersion compared to the reference Gaussian. The general (4,4) pulse shape remains un-degraded compared to the reference Gaussian.

Houston 3-D model

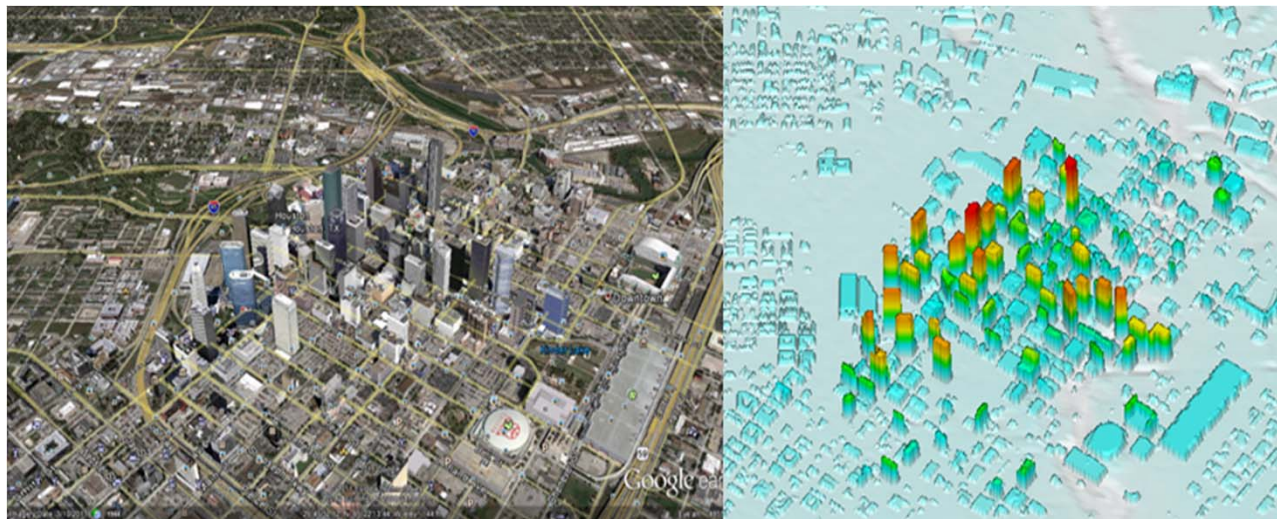
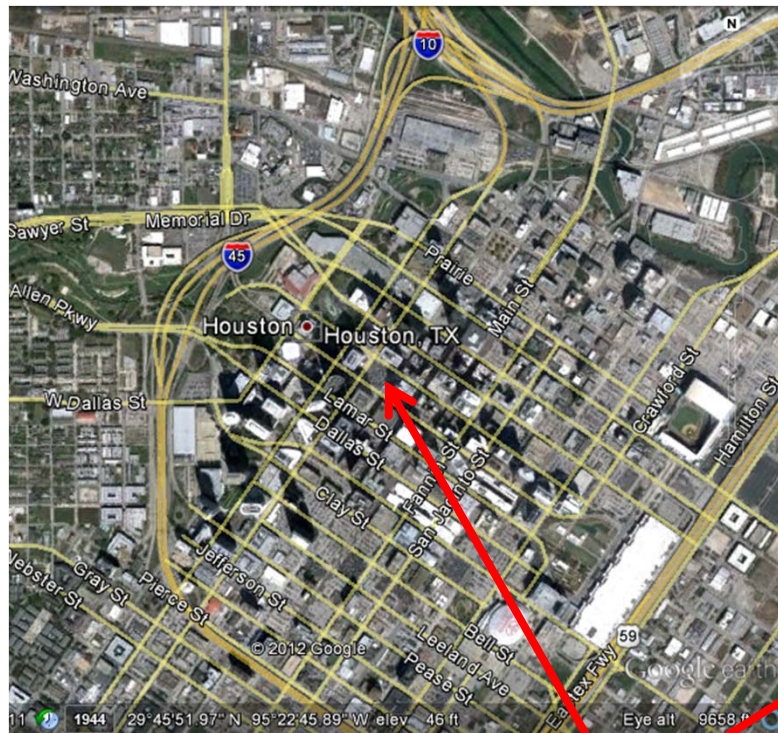
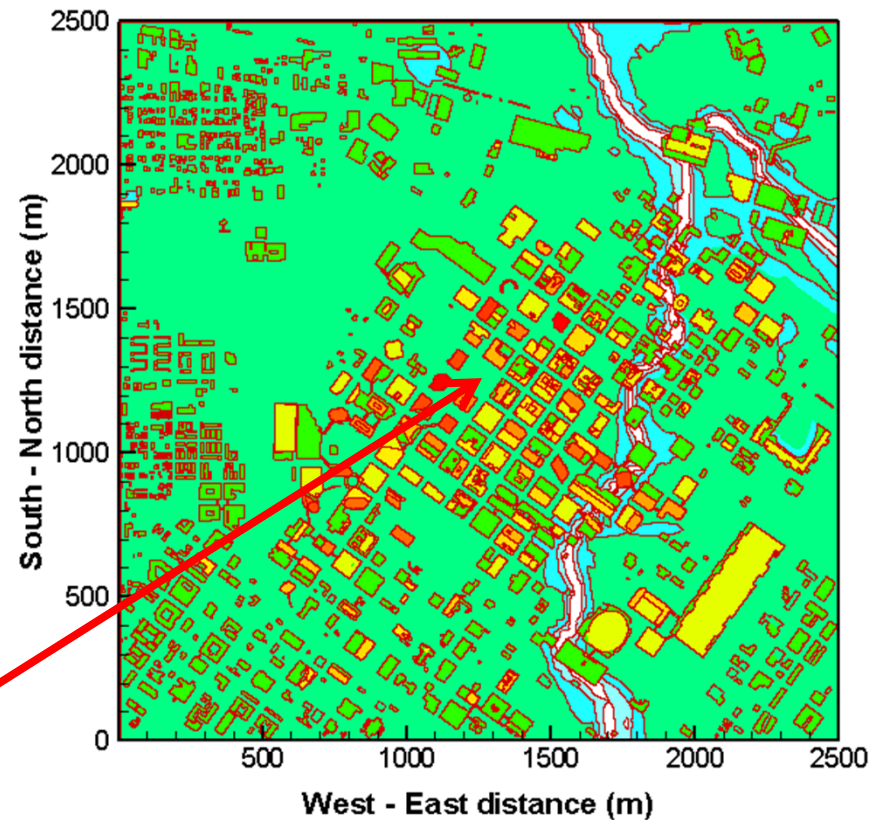


Figure 1. Left: Google image of downtown Houston. Right: Corresponding model grid representation. The modeled Houston area is approximately 2.5km x 2.5km.

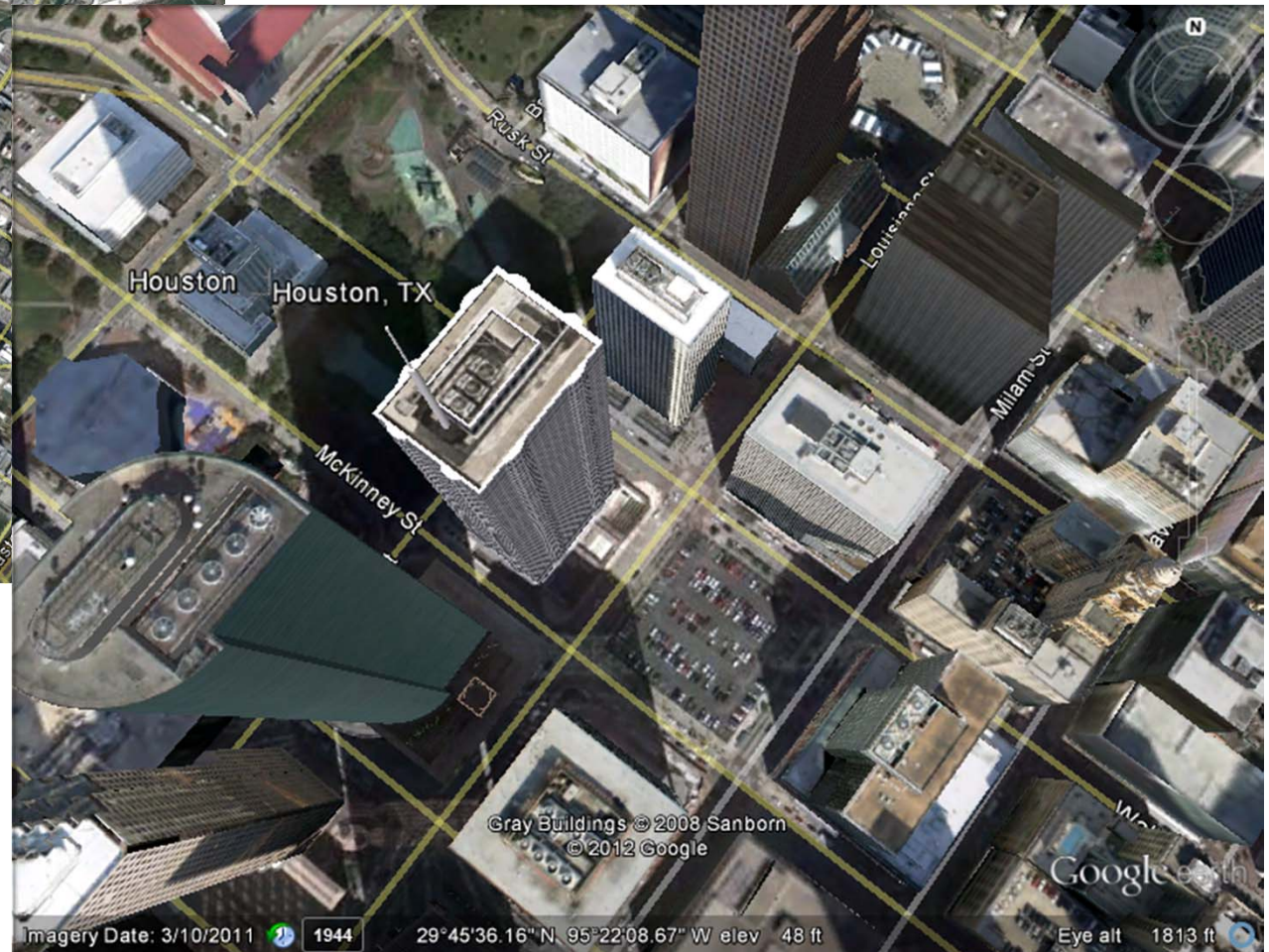
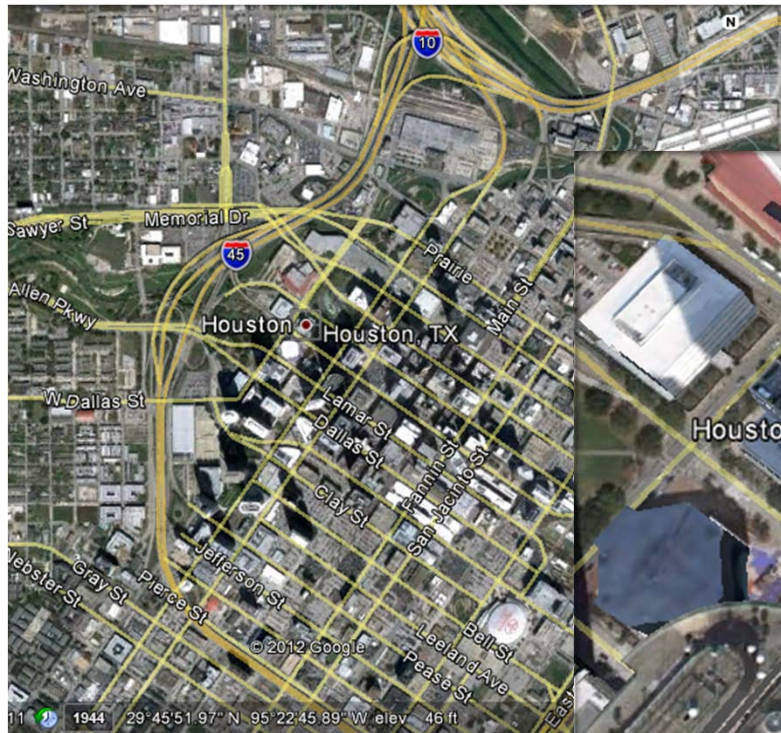
NUDET location in Houston model grid



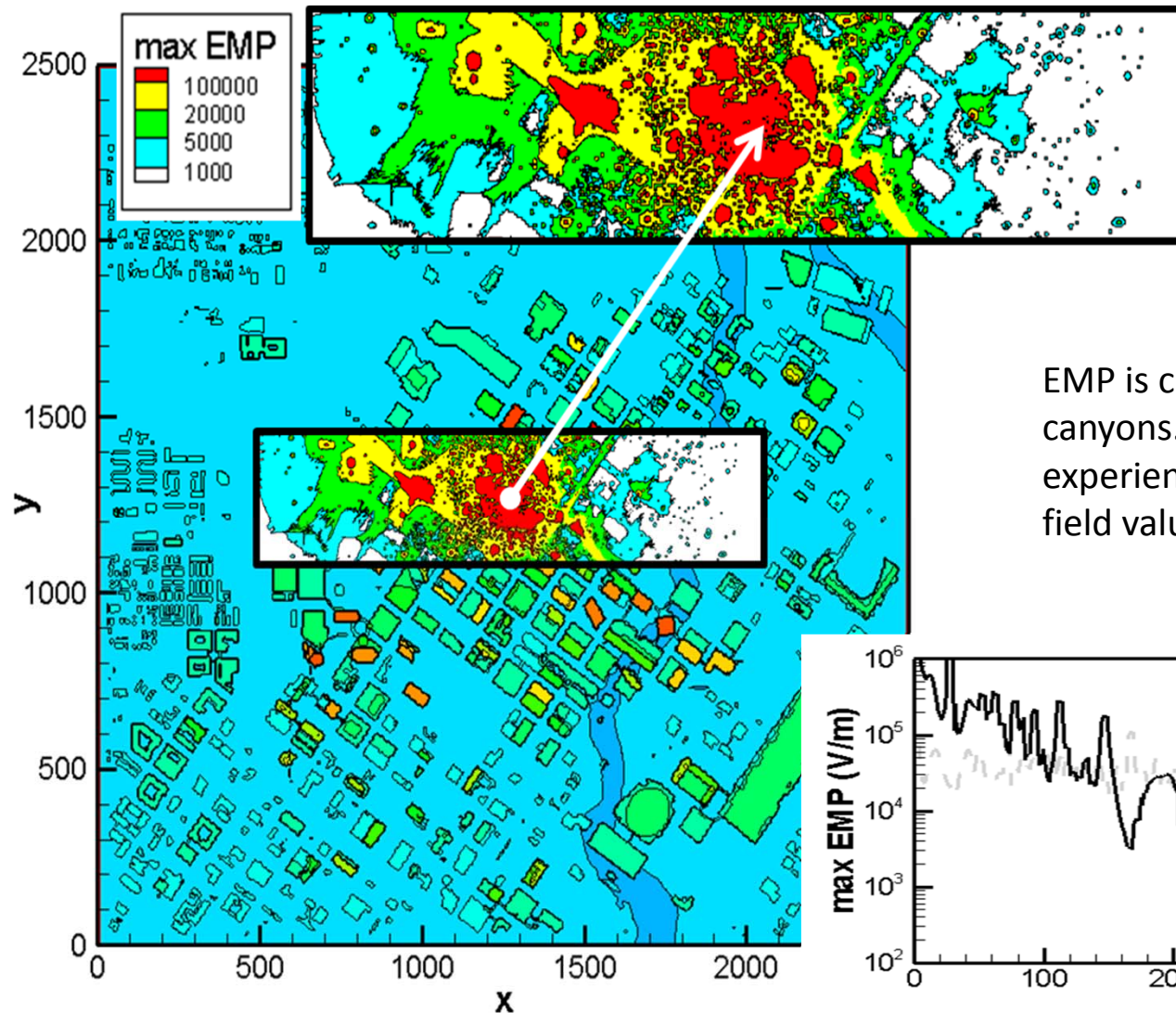
NUDET location



NUDET location and surrounding buildings

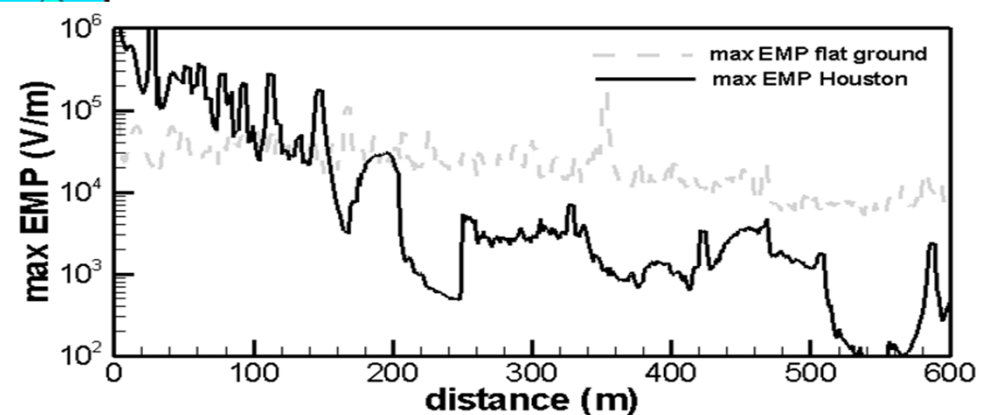


3-D Urban EMP FDTD; downtown Houston, TX

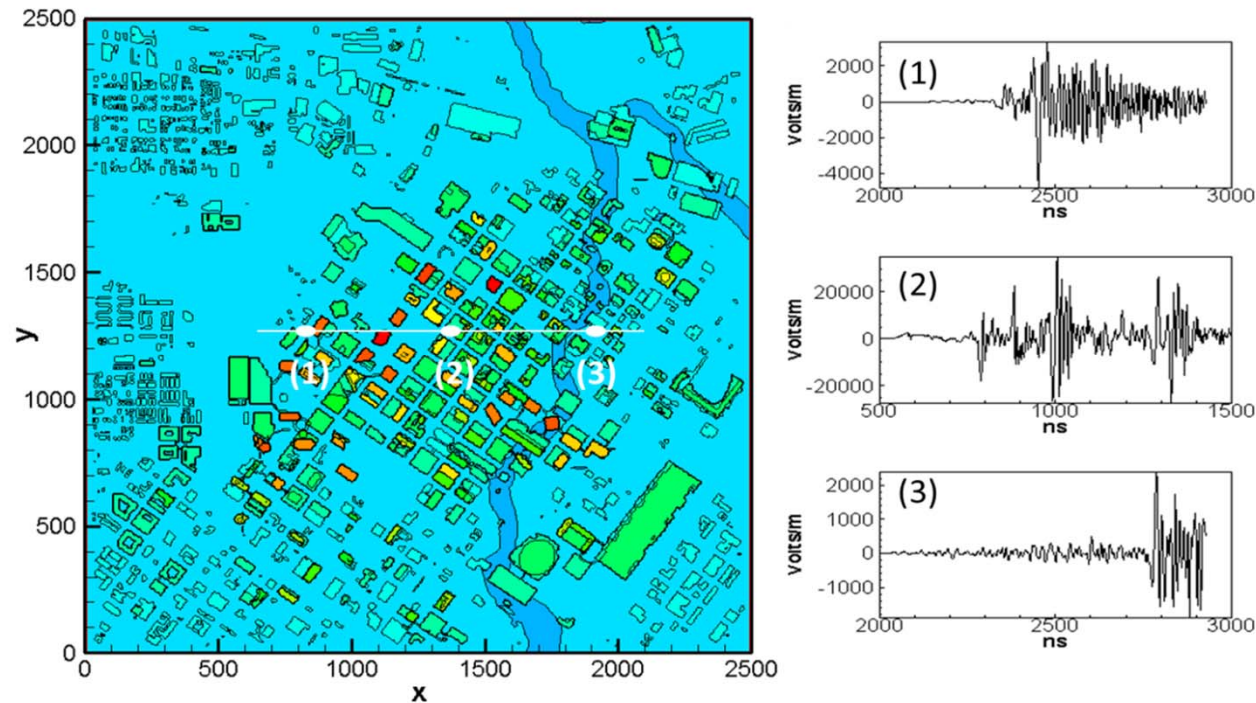


Horizontal cross section of downtown Houston - expanded inset showing the maximum magnitude EMP (V/m).

EMP is channeled outward along street canyons. Yellow and red contoured areas experience maximum electromagnetic field values above 20 kV / m.

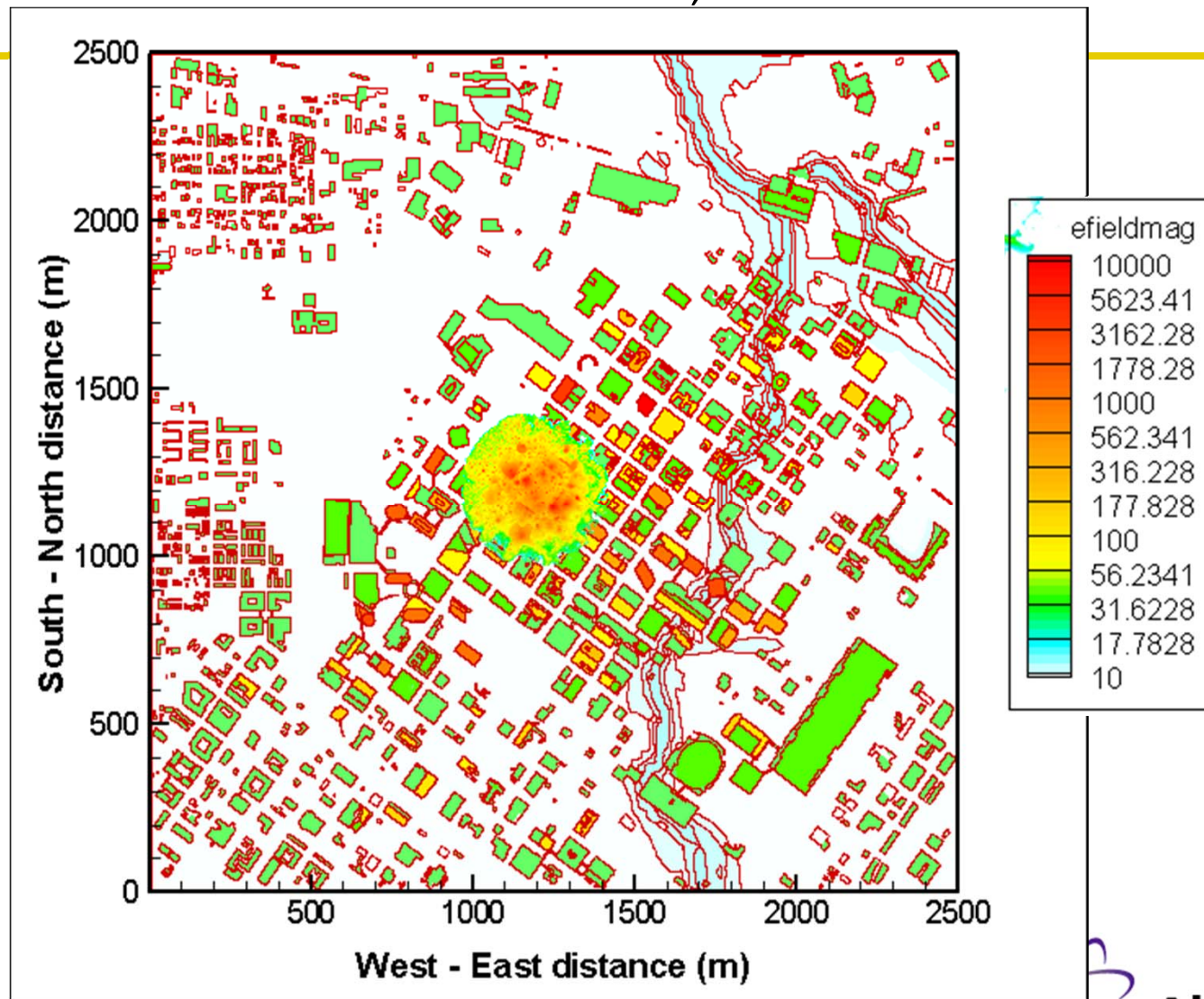


3-D Urban EMP code FDTD; downtown Houston, TX

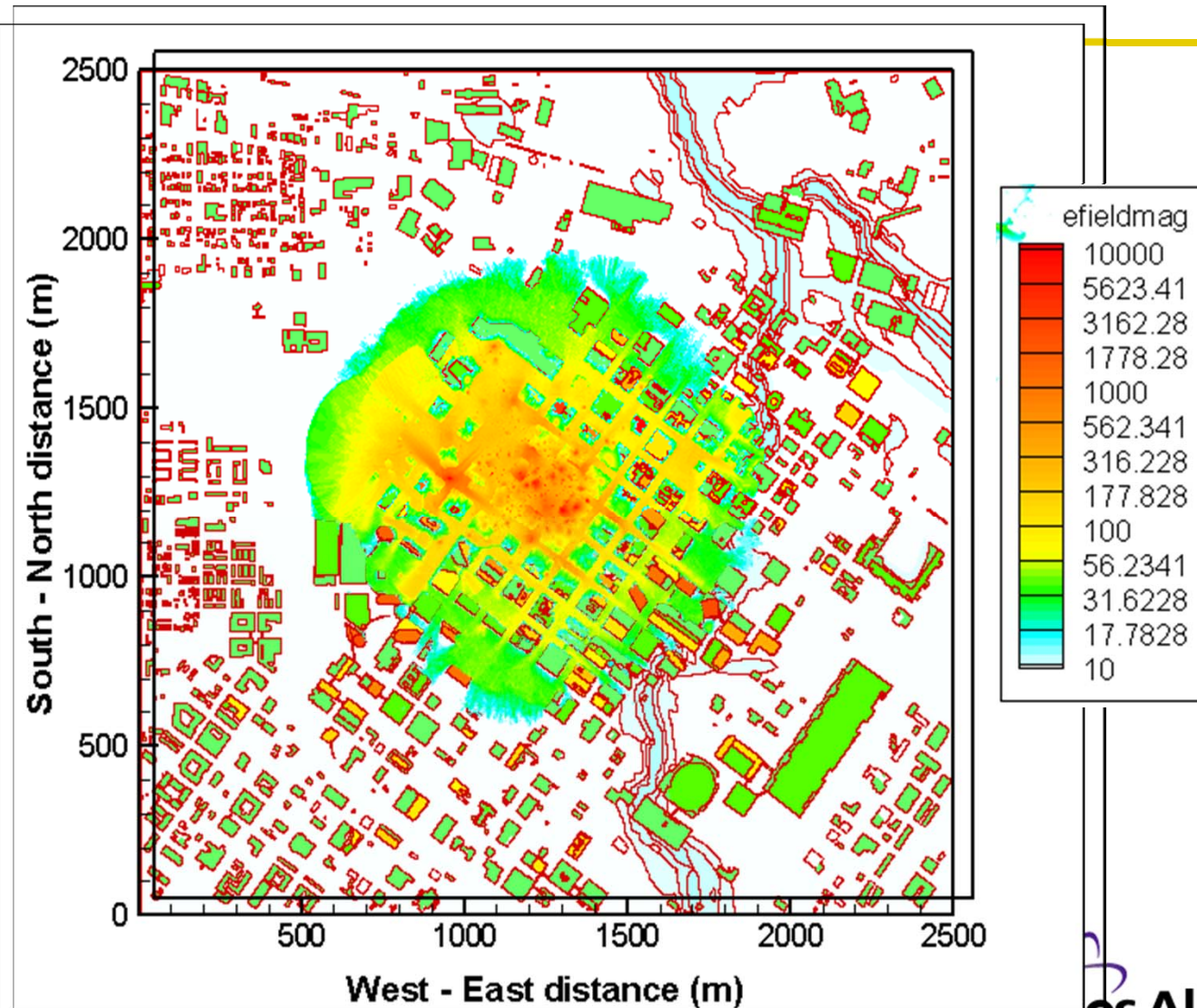


Horizontal cross-section of Houston downtown area, showing points at which simulated EMP signals were sampled. The EMP signals for sample points 1, 2, and 3 (from left to right on the map) are shown to the right. The strength of the EMP signal is strongly dependent on the distance from the NUDET detonation (open parking lot) and the urban topography.

Maximum magnitude EMP 500 ns downtown Houston, TX

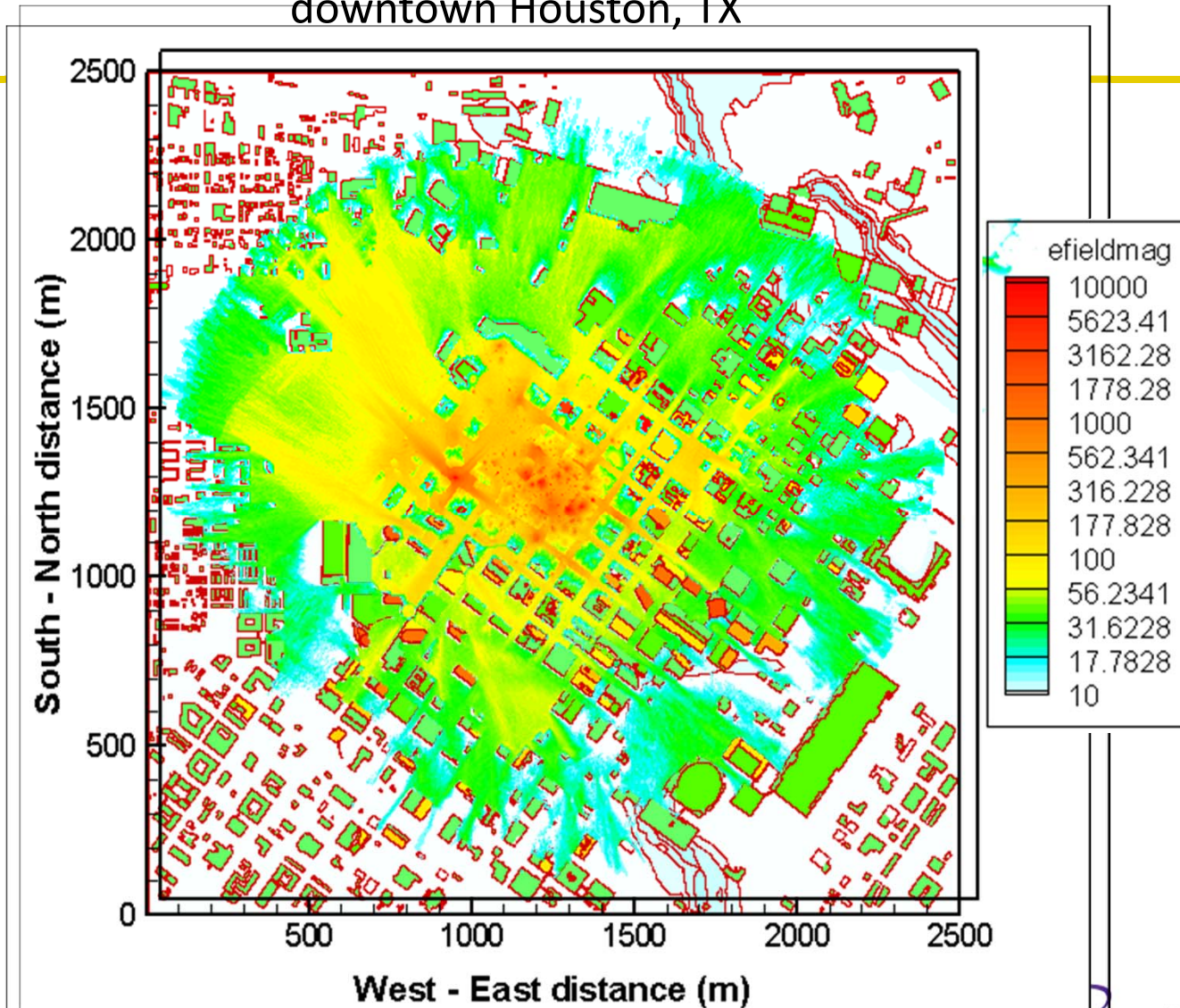


Maximum magnitude EMP 1500 ns downtown Houston, TX

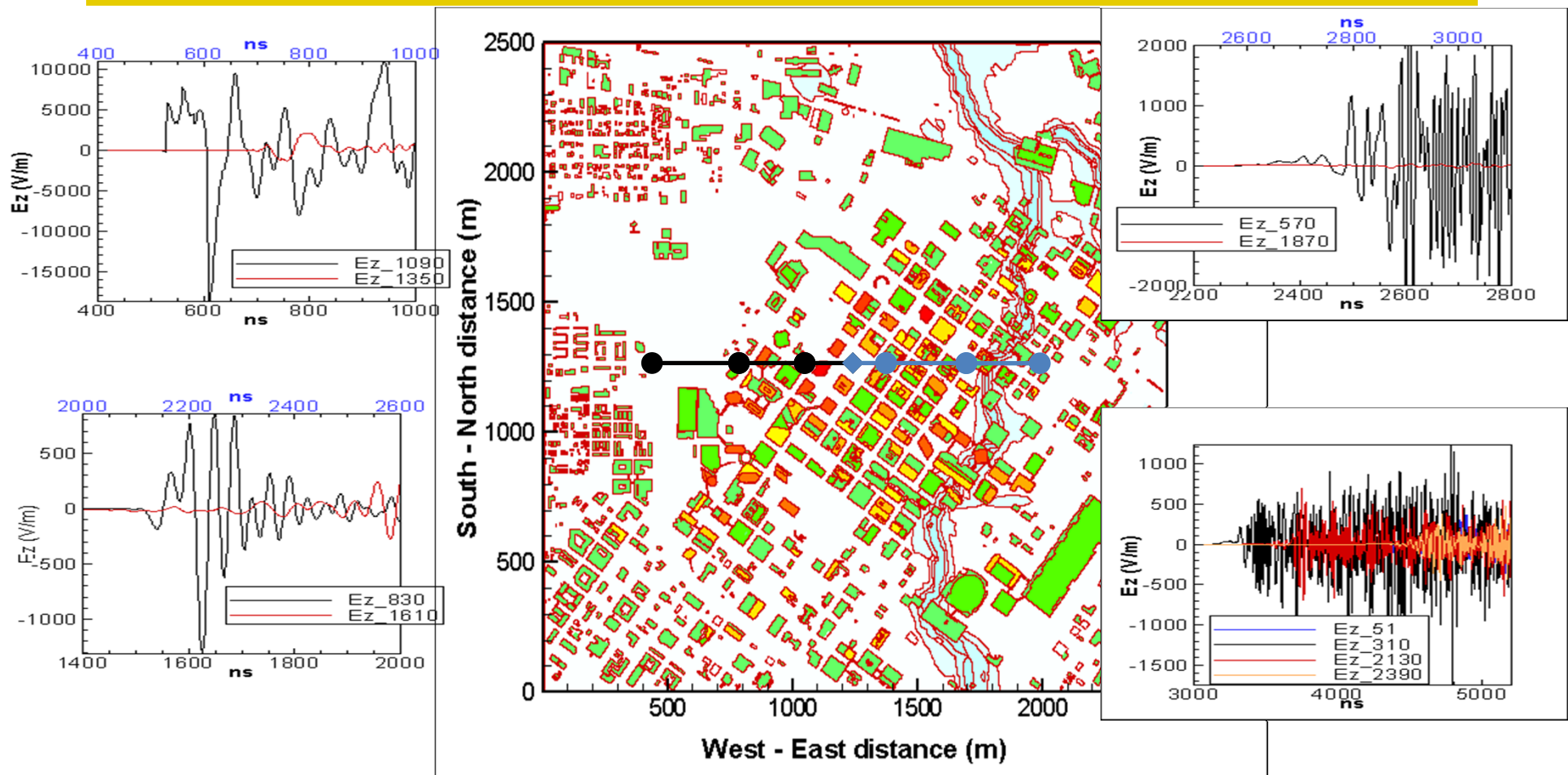


Maximum magnitude EMP 2500 ns

downtown Houston, TX



Vertical component EMP for selected probes



Comments

- MCNP and LANL FDTD are coupled
 - LANL FDTD included as subroutine to MCNP
 - Secondary electron calculation included to account for conductivity
 - Proceeding with validation experiments using output from HEMPV
 - Geomagnetic fields in MCNP.
 - Two-way communication of Fields between MCNP and FDTD for self-consistent EMP
- Houston EMP FDTD results
 - Source region currents and large buildings greatly complicate EMP
 - Larger domain needed to get EMP above the city skyline and at ~10-20 km range.
 - LANL schemes allow for simulation of EMP in electrically large domains
 - 4th order broadband isotropy and 2nd or 4th order dispersion
 - Implemented on Yee grid
 - Scattering and attenuation at discrete building interfaces needs work

Present work

-
- Continued testing of MCNP/FDTD integration
 - Sub-grid physics from ezFDTD to LANL FDTD
 - Improvements to PML
 - More realistic and detailed city models (materials, walls, steel beams, etc)

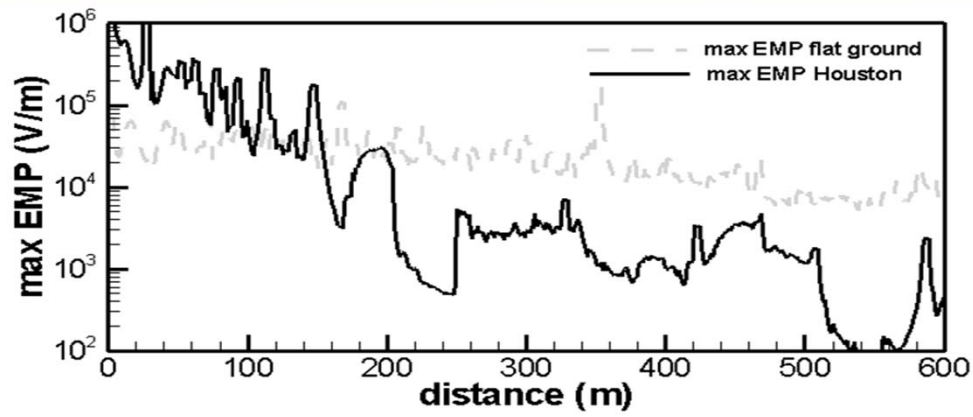


Figure 5. Maximum EMP versus distance from NUDET origin. Comparison is for the Houston NUDET with origin in the open parking lot, and an equivalent NUDET at same location, but with no urban topography. The shielding effect of the surrounding Tower complex is evident, as well as the effect of the urban canopy farther away from the detonation.